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SHORT PULSED BEAM EXTRACTION FROM KURNS FFAG

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Abstract

Short pulsed proton beams of 8 ns has been extracted from FFAG accelerator in KURNS. Bunch rotation after adiabatic de-bunching was used at highest energy orbit.

INTRODUCTION

Accelerator complex of fixed field alternating gradient (FFA) synchrotrons [1] has been developed in Kyoto university integrated radiation and nuclear science (KURNS), aiming to demonstrate the basic feasibility study of accelerator driven sub-critical system (ADS). The ADS studies using this accelerator complex connected with Kyoto university critical assembly (KUCA) was started in 2009 [2]. In 2011, the output beam intensity reached 1 nA in 30 Hz operation by employing charge stripping beam injection from H^- beam line [3]. Since then, many kinds of experiments, not only about ADS study, has been carried out using our beam.

In 2019, new experiments project [4] for ADS studies was started to investigate nuclear data. The ToF measurements of secondary particles coming from beam target was essential in the experiments, so that the short pulsed proton beams like $\sigma \simeq 10$ ns was required. In order to extract such a short pulsed beam, the bunch rotation method was tried in the highest energy orbit of the FFA Main Ring. The paper reports the experimental studies of bunch compression and extraction.

METHOD

Main Ring

Main FFAG synchrotron accelerates proton beams from 11 MeV to 100 MeV or 150 MeV. This machine is so called *radial sector scaling FFA*, at which the main magnetic field $B(r)$ is proportional to r^k. Since the field is constant of time t, synchronous energy is determined by only rf frequency.

Injected beams are captured by a moving rf bucket, accelerated at constant rate, and extracted with a fast kicker magnet in normal operation. The acceleration rate corresponds to 4 kV× sin 20^o over all energy range. The final rms bunch length at ~ 100 MeV is around 26 ns in rms.

Details about the accelerator and beam parameters are seen in Ref. [5].

Short bunch

Short bunch is created in the main ring by bunch rotation method at 107 MeV orbit. Figure 1 shows schematically the rf operation for short bunch extraction. Accelerated beam is re-captured by stationary rf bucket, and the rf voltage is slowly reduced in order to compress the energy spread of particles (adiabatic de-bunching). After the de-bunching, the maximum rf voltage is applied to excite the quadrupole mode synchrotron oscillation (bunch rotation). Minimum bunch length is obtained after 1/4 synchrotron oscillations, which is extracted by fast kicker magnet.

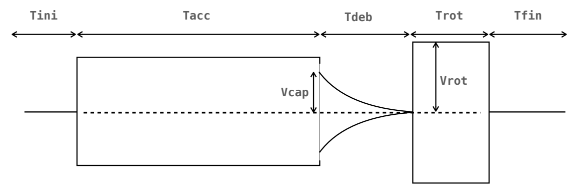

Figure 1: Rf operation scheme for short bunch extraction.

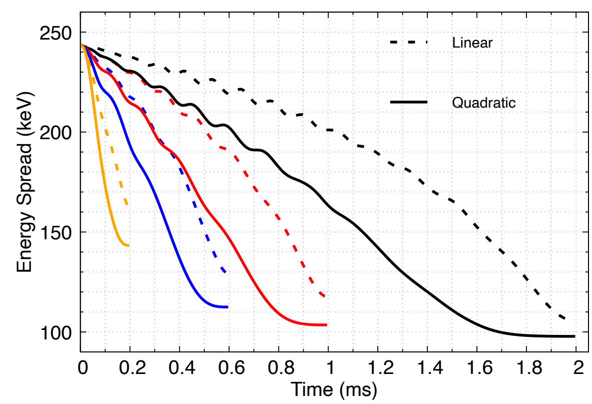

Figure 2: Energy compression by adiabatic de-bunching.

Effect of the adiabatic de-bunching was estimated by simulation studies. Figure 2 shows rms energy spread during de-bunching. Here the rf amplitude was decreased as

$$\tilde{V}(t) = V_0 \left(1 - \frac{t}{T_{deb}}\right)^n \quad (1)$$

with $n = 1$ (linear) or $n = 2$ (quadratic), where T_{deb} is the de-bunching time constant. Among them the parameters T =1 ms and $n = 2$ are chosen in the experiments. The adiabatic parameter, defined by

$$\epsilon = \left| \frac{\mathrm{d}}{\mathrm{d}t} \frac{1}{\omega_s} \right| , \quad (2)$$

is 0.10 in that case.

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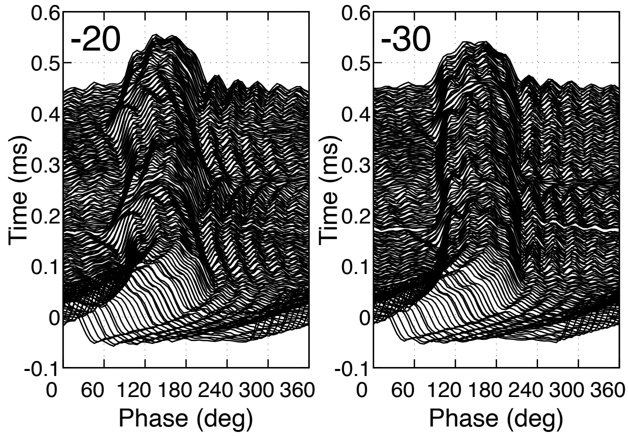

Figure 3: Synchrotron oscillations after recapture with $\Delta\phi = -20$ deg (left) and -30 deg (right).

EXPERIMENTS

Recapturing

In order to determine experimentally the recapturing rf parameters, stationary rf with constant voltage was applied right after reaching the top energy and the coherent oscillations were monitored. First, The rf phase offset to compensate the accelerating phase was surveyed every 5 deg between −90 deg and 90 deg. Figure 3 compares the results between $\Delta\phi$ =−20 deg and −30 deg. The dipole mode oscillation is clearly observed for $\Delta\phi = -20$ deg, but it is minimized for −30 deg. Similarly the recapturing rf voltage was determined to 85% of the accelerating voltage by minimizing the quadrupole synchrotron oscillations at the flat top.

Bunch Rotation

The amplitude of the flat top rf was decreased as Eq. (1) with T_{bun} = 1 ms, and the maximum rf voltages was applied after that (Fig. 4).

Figure 5 shows the output from bunch monitor in the ring. The beam reached the top energy at time t =0 ms, adiabatically de-bunched for 1 ms, and quadrupole oscillation was excited after that. In the Fig 5 strong envelope oscillations were observed after 1 ms. The frequency of the monitored envelope oscillation was 2 × 5.6 kHz which is close to the expected value 2 × 5.8 Hz; The small difference is due to the amplitude detuning of the synchrotron oscillation.

The bunch length was decreased as the envelope oscillations, and it took minimum value at after 1/4 synchrotron oscillations (44 μs). Measured bunch length there was 25 ns in FWHM and 8 ns in root mean square, while it was 80 ns in FWHM before de-bunching. The beam was extracted by a fast kicker magnet at this timing. The extracted beam measured at a bunch monitor in front of the target chamber has the same pulse length.

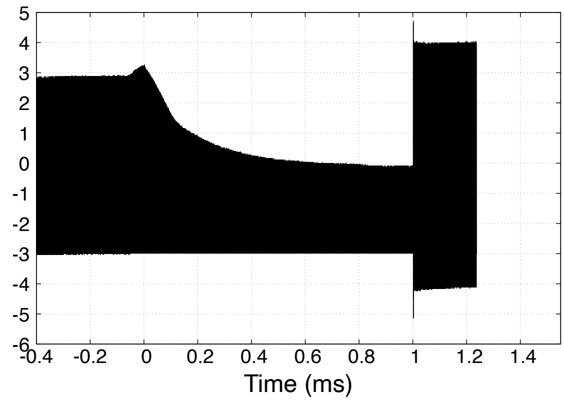

Figure 4: Rf voltages to make short bunch.

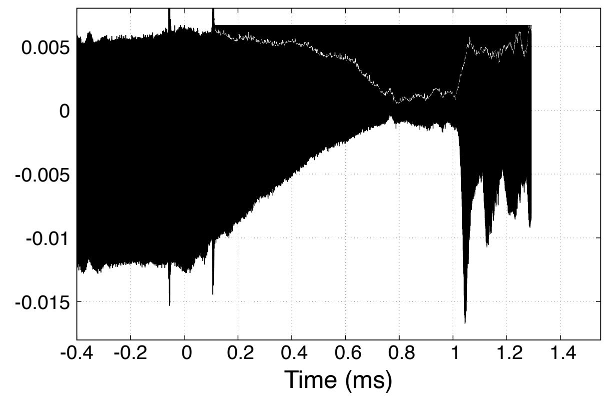

Figure 5: Output of electrostatic bunch monitor at top energy (107 MeV).

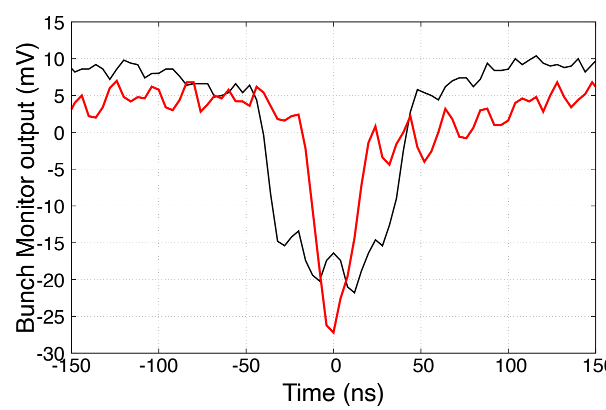

Figure 6: Short bunch (Red) and normal bunch (Black) profiles in the ring.

Long Pulse Extraction

The long pulse beam extraction was also tried. The beam was extracted with the same rf operations but right after finishing the de-bunching (1 ms). Though the beam has not bunched, the extracted bunch length is limited by the flat top length of the kicker field. Figure 7 shows the extracted

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beam profile, together with that of short pulse mode. The profile has the flat top of ~ 90 ns.

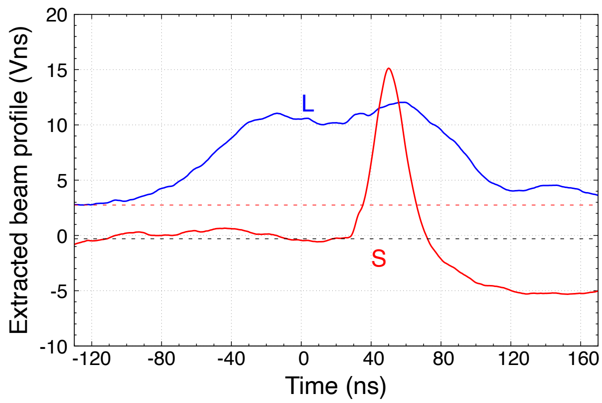

Figure 7: Extracted beam profile in (S) short pulse mode and (L) long pulse mode. They are measured by a bunch monitor in front of the target (positive output).

CONCLUSION

Short pulsed proton beams of 107 MeV were extracted from the FFA at KURNS. Bunch rotation after adiabatic debunching was used. The rms length of the extracted beam was 8 ns.

ACKNOWLEDGEMENTS

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